HST End of Mission (EOM) Options
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The following discussion lists all EOM options that have been or are currently being considered, together with the salient aspects of each.

Uncontrolled Re-entry: Without intervention the HST orbit will eventually decay and the vehicle will re-enter and breakup in an uncontrolled manner. The time of re-entry is highly dependent on the timing and level of solar activity and whether re-boosts have been performed during the final servicing missions. In the case of no further re-boosts and a $+2\sigma$ peak level of solar cycle 24, re-entry is predicted in 2013. A re-boost of 4 nautical miles in SM4 (assumed mid-2005) is plausible, and this would extend the date of re-entry by approximately 24 months to 2015. Note that, approximately one year prior to re-entry, HST will start to encounter longer slew times and degraded science due to the increase in atmospheric density, which will overwhelm the precision control ability of the pointing control system. Although portions of HST will burn up in the atmosphere during re-entry, a significant debris field is expected to hit the surface of the earth. In particular the massive primary mirror and its surrounding titanium main ring – the structural backbone of HST – will almost certainly impact the earth. Calculations with the Johnson Space Center's ORSAT (orbital re-entry spacecraft analysis tool) program, which includes projections of human population densities versus time, predict a 1/700 probability of human casualty resulting from an uncontrolled HST re-entry. The current NASA requirement is a probability of less than 1/10,000. The present official policy of the NASA Office of Space Science is that the HST will not be allowed to reenter in an uncontrolled manner.

Return to Earth Via the Space Shuttle: This is the currently planned baseline option to which the HST Program Office is working. The technical implementation of a return to earth mission has been studied in detail by the HST Program. In summary, the execution of the mission is similar in scope to a typical servicing mission of the kind successfully executed by the HST Program and its partners at JSC and KSC four times in the past. Because the HST must be stable and safe for shuttle retrieval, this option must be executed while the HST is functional and possesses sufficient redundancy in key systems to ensure it remains so during mission execution – e.g. thermal control, pointing stability sufficient for grappling, communications, commanding and telemetry. With complete loss of pointing control, HST would be semi-stable in a "gravity gradient" mode and still could be grappled with the Shuttle's remote arm. However, extended periods of gravity gradient operation could lead to HST structures becoming too cold, and possibly unsound, so that they would no longer be safe for landing within the Shuttle payload bay. Thus, the loss of redundancy in key systems, or the threat of irrecoverable entry into gravity gradient mode, would require an early "call-up" mission to assure that HST can be safely retrieved and returned to earth by the astronauts. There is a small but nonnegligible chance (of order 10%) that a retrieval mission would be unsuccessful, and that the HST would subsequently undergo an uncontrolled re-entry. Taking this into account, the overall probability of human casualty resulting from the return-to-earth option is about 1/7000, still somewhat worse than the NASA standard 1/10,000 (this does not include probabilities associated with loss of the shuttle itself).

The current HST Program budget for the execution of a retrieval and return-to-earth mission totals approximately $137M, with detailed mission planning commencing in 2007 for a 2010 mission. It is assumed that the costs of the Human Space Flight elements of the mission are covered outside the HST budget, as they have been for all other servicing missions. Although no official policy has been promulgated to the HST Program by NASA Headquarters, informally it is expected that the retrieval and return to Earth of the HST by Shuttle astronauts will be judged of insufficient value in relation to the risks to crew and shuttle vehicle, and that other EOM options must be identified.

Boost to a High Altitude Disposal Orbit: The feasibility of raising the HST orbit to an acceptable disposal altitude (2500 km) has been examined. This is far beyond the capability of the space shuttle and would require the addition of a large (22,000 lbs) propulsion system to the HST. This option is no longer under study, as the propulsion system required has been deemed impractically large and expensive.

Space Shuttle-Installed Propulsion Module Followed by Continuing Science Operations: The installation of a propulsion module carried to orbit on the space shuttle, potentially on a future servicing mission, would enable a controlled, safe re-entry when it is decided to terminate the HST mission. The HST Program completed a preliminary study of this option in 2001. It is currently the subject of an ongoing NASA feasibility study led by Marshall Space Flight Center. In this option it is essential that the installed propulsion module not unduly interfere with ongoing HST science operations – e.g. liquid propellant "slosh" should not impart unacceptable "jitter" to HST pointing control, nor should the module add so much mass to the HST as to yield unacceptably slow slewing rates. The module needs to be an autonomous, self-contained system requiring no external or HST-provided guidance, navigation and control services. It should require minimal (if any) connection to HST spacecraft systems (e.g., for electrical power).

In the preliminary (2001) study, five propulsion systems were considered: solid rocket motors, monopropellant, bipropellant and dual-mode systems, and ion engines. Of these only the electric ion engine was eliminated from further study (because of inadequate power). A field survey of existing systems and technologies was conducted in the preliminary study. Numerous potential vendors were identified that had prior experience with moderately priced, low-risk, low-development options for propulsion stages as utilized in prior NASA robotic missions (e.g., Mars Global Surveyor, Orbital Star-2, Triana, Deep Space-1, Chandra, COMSAT). The study concluded that only minor HST interface changes would be necessary and that these should be straightforward. Installation would require only one space walk However, further study is warranted to provide independent verification of the technical soundness of the proposed approach. . Once installed, such a propulsion module would give considerable flexibility to HST operations, allowing re-boost if needed for continuing operations and de-orbit when needed without further reliance on the shuttle. Its principal drawback is that if it does not work properly when commanded, another shuttle mission would be required to repair or replace it. Otherwise uncontrolled re-entry is inevitable. Of course the shuttle mission to install the propulsion module could also do other maintenance and upgrades of HST, thus extending its scientific lifetime.

Recently Lockheed Space Systems has provided to the Marshall-led study team a description and cost estimate for a propulsion module that would meet the requirements of this option. The estimated cost is approximately $60M. It must be noted that the more detailed feasibility studies of this option currently in progress may or may not reach the same conclusions, as did the 2001 preliminary study.

Space Shuttle-Installed Propulsion Module After Science Operations Have Ceased: This is a variation of the prior option. In this case the performance characteristics of the propulsion module would not be constrained by issues of non-interference with continuing HST science operations. The module would presumably be simpler, and the interfaces with the HST would be very simple. Even if HST had spent considerable time in gravity gradient mode prior to the installation mission, and had become very cold and structurally unsound, this would not be a safety issue as it is in the case of shuttle retrieval and return to earth. The module still must operate reliably when commanded; otherwise uncontrolled re-entry or a follow-up shuttle mission would be the consequence. In this option there is no possibility of servicing HST to extend its scientific lifetime. One must consider if the objective of such a mission – to facilitate the controlled re-entry of a dead HST – is commensurate in value with the corresponding risks to the shuttle crew and vehicle.

Robotically Installed Propulsion Module Followed by Continuing Science Operations: A propulsion module launched on an expendable rocket could dock with the HST and provide the capability for a controlled re-entry at the appropriate time in the same manner as the shuttle-launched propulsion module described above. Currently there exists no capability within NASA for passive, unmanned rendezvous and docking with robotic spacecraft. This lack of technical maturity presents significant challenges in the near term, including feasibility, cost and schedule compatibility with an HST end of mission in 2010. Possible contamination of HST during rendezvous and capture is also a concern. This propulsion module would need to satisfy all the same constraints on compatibility with continuing HST science operations, as its counterpart in the shuttle-installed option described above. However, given that HST science operations would be on-going at the time of this mission, HST would be guaranteed to be stable and controllable – a cooperative partner for rendezvous and docking. A virtue of the robotic approach is that if the mission failed or if the propulsion module failed to function properly, further attempts could be made – additional expendable rocket missions could be undertaken – without reliance on the availability of the shuttle. If this option, or the next one, were selected, it is possible that space walk time on SM4 would have to be set aside for the installation of targets or other docking aids onto HST. Since the current payload slated for SM4 already fully subscribes the available space walk time, this means that other important items might have to be removed from the manifest. With no servicing mission planned subsequent to SM4, no further opportunity would be available to install such items on HST.

Robotically-Installed Propulsion Module After Science Operations Have Ceased: Analogous to the shuttle-installed propulsion module options described above, this is a variation on the prior robotic installation option. The propulsion module would be launched and docked to HST "on need" when it is decided that science operations are no longer viable. This approach significantly relaxes the design requirements for the propulsion module, because the science mission will have been terminated. It potentially offers a somewhat longer time to develop the required unmanned rendezvous and docking technology. At worst HST would be in a semi-stable gravity gradient attitude state, so that rendezvous and capture should be feasible. Once again, should the first robotic mission fail for any reason, presumably further attempts could be made at the cost of additional expendable rocket launches and the cost of replicating the propulsion module, without having to invoke a follow-up shuttle mission with its attendant risks. This option is also under active study by Marshall. Its cost is roughly estimated to be around $230M.

Conclusions: None of the available options described above can be considered "ideal". Each has significant elements of risk or issues of feasibility or both. However, two of the options stand out as being more attractive than the others – a shuttle mission to install a propulsion module, followed by continuing science operations, or a robotically-installed propulsion module after science operations have ceased. To reiterate, further integrated systems-level studies are required to determine the feasibility, reliability, and engineering details of these or any other propulsion module option.

The attractive shuttle mission option is a relatively straightforward extension of the HST Program's series of highly successful servicing missions – 4 missions to date consisting of 18 consecutive fully successful space walks to maintain and upgrade the HST. The major new aspect of such a mission would be procuring a suitable propulsion system that would be compatible with HST's requirements for maintaining its performance and operational efficiency.

The other potentially attractive option, robotic installation of a propulsion module after HST's operational life is over, could be carried out independently of the Human Space Flight program. Some aspects of the module's design would be simplified because it would not have to be compatible with HST scientific performance requirements. The major drawback of this option is that the technology is currently immature. It is not clear how much time or money will ultimately be required for the development of such a system. Re-boosting Hubble to a somewhat higher orbital altitude would delay its re-entry and give this technology more time to mature. For example, a 4 nautical mile re-boost in SM4 would delay Hubble's re-entry by about 2 years, from 2013 to 2015, although science operations would almost certainly have ceased long before then, without additional servicing beyond SM4.

If it were decided to extend the scientific lifetime of Hubble by means of an additional servicing mission in 2009 or 2010, in lieu of the currently base-lined shuttle retrieval and return mission, either the astronauts could install a prop module at that time, or a re-boost of up to 10 nautical miles could be executed,which would extend Hubble's orbital life by a decade or more, allowing more time for NASA to develop a suitable robotic system.

In summary, if SM4 is executed in 2005 as currently planned, the odds are against continued HST science operations much beyond 2009-2010. A small re-boost of HST in SM4 would forestall its re-entry by about two years, allowing more time for a robotic retrieval mission and controlled re-entry. A shuttle-based servicing mission in the 2009-2010 timeframe would enable science operations to continue to approximately 2014-2015 or potentially longer. A prop module installed by the astronauts in 2009 or 2010 would provide the capability for controlled de-orbit and re-entry at any desired time in the future. A re-boost during such a mission could extend Hubble's orbital lifetime for a decade or more, and provide significant additional time in the development of a robotically installed propulsion module.